International Journal of Teaching and Learning in Higher Education 2014, Volume 26, Number 2, 232-250
http://www.isetl.org/ijtlhe/ ISSN 1812-9129

Science Teaching Beliefs and Reported Approaches Within a Research University: Perspectives from Faculty, Graduate Students, and Undergraduates

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This study explores and compares the perspectives of three populations (faculty members, graduate students, and undergraduates) toward science teaching in the College of Chemical and Life Sciences at a research-intensive university. In particular, we investigate the role of faculty professional development in reforming undergraduate science education. In Spring 2011, we collected data through an online survey of 71 faculty members, 99 graduate teaching assistants, and 288 undergraduates in their senior year. We used mixed mode data analysis to examine the perceived importance of skills for undergraduates as viewed by the three populations and the reported practices used by faculty and experienced by students. We found that across all three groups most of the respondents placed a high value on active learning and conceptual understanding, which is consistent with national recommendations. However, when comparing reported beliefs with reported practices, we found that faculty members do not always incorporate active learning techniques. In order to bridge this gap, we suggest providing faculty with professional development opportunities, moral support from peers, and instructional support from science education and instructional technology specialists. Our findings support this recommendation, as faculty who were in teaching-focused communities reported using innovative practices more than those not in communities.

This study examines the perspectives of three populations (faculty members, graduate students, and undergraduates) toward science teaching in a research-intensive university to investigate the role of faculty professional development in reforming undergraduate science education. We aimed to determine (1) what skills the three populations believed were most important for undergraduates to acquire; (2) what teaching approaches faculty members believed were most important; (3) what teaching approaches faculty members reported using; (4) what teaching approaches students reported experiencing, and if these were consistent with faculty reports; and (5) what professional development opportunities faculty believed would help them with their teaching.

There has been a strong national call (American Association for the Advancement of Science [AAAS], 2010; Association of American Medical Colleges and Howard Hughes Medical Institute Committee [AAMC-HHMI], 2009; Association of American Universities [AAU], 2011; National Academies, 2006; National Research Council [NRC], 2003; Presidential Council of Advisors on Science and Technology [PCAST], 2012; Woodin, Carter, & Fletcher, 2010) to improve professional development for university science, technology, engineering, and mathematics (STEM) faculty in response to research indicating a high level of dissatisfaction with the instructional methods used to teach STEM undergraduates (Seymour & Hewitt, 1997; Henderson, Beach, & Finkelstein, 2011; Henderson, Beach, Finkelstein, & Larson, 2008). More generally, national recommendations stress the importance of promoting critical thinking as an outcome of undergraduate study, especially through the following actions: (a) promoting conceptual understanding rather than memorization of isolated facts (Ebert-May & Hodder, 2008; Mayer, 2002; Redish, 2003, Smith, Wood, & Knight, 2008; Wieman, 2007); (b) using active learning student-centered approaches, such as cooperative and collaborative learning, to engage students in their learning process (Freeman et al., 2007; Injaian, Smith, Shipley, Marbach-Ad, & Fredericksen, 2011; Jenson & Lawson, 2011; Kitchen, Bell, Reeve, Sudweeks, & Bradshaw, 2003; Knight & Wood, 2005; Senkevitch, Smith, Marbach-Ad, & Song, 2011; Udovic, Morris, Dickman, Postlethwait, & Wetherwax, 2002; Walker, Cotner, Baepler, & Decker, 2008); and (c) fostering an understanding of the nature of scientific research and its applicability to everyday life (AAAS, 2010; Handelsman, Miller, & Pfund, 2007).

Faculty Members' Beliefs About Teaching

Despite the repeated national calls to change teaching and adopt the above national recommendations, many faculty members are satisfied with traditional instruction, which is based mainly on lecturing, and remain skeptical of other methods (Hanson & Moser, 2003; Henderson et al., 2008; Luft, Kurdziel, Roehrig, & Turner, 2004; Miller, Martineau, & Clark, 2000). In most universities faculty rarely receive any formal training in teaching as graduate students or as faculty members (Cox, 1995; Golde & Dore, 2001; Handelsman et al., 2007; Luft et al., 2004), so the only model for them to replicate is what they experienced as undergraduates, which mainly involved extensive lecturing. The literature suggests that faculty beliefs toward teaching are constructed from these previous experiences as students (e.g., Adamson et al., 2003; Anderson & Helms, 2001; van Driel, Beijaard, &

Verloop, 2001). Bryan and Atwater (2002) described “beliefs” as the structure and content of a person’s thinking that are presumed to drive her/his actions. In accord with their definition, it is generally agreed that what teachers believe in—as it relates to their philosophy of teaching, their role within that process, the role and expectations of the students for learning, the role of science curricula, and context for instruction—will be an essential foundation for what occurs in their classroom (Blake, 2002).

Indeed, studies have shown that faculty beliefs are often closely aligned with their approach to teaching (e.g., Martin, Prosser, Trigwell, Ramsden, & Benjamin, 2000) and can impact student achievement both positively and negatively (Adamson et al., 2003; Brickhouse, 1990; Cronin-Jones, 1991; Gallagher & Richmond, 1999; Munby, Cunningham, & Lock, 2000; Tobin & McRobbie, 1996). For example, there is a growing body of evidence that when teachers believe in the value of student engagement, they are more likely to promote it in the classroom, and as a result students learn more effectively (Martin & Balla, 1991; Prosser, Trigwell, & Taylor, 1994; Trigwell, Prosser, & Taylor, 1994; Trigwell, Prosser, & Waterhouse, 1999).

Faculty beliefs about teaching can be influenced by their experiences in the classroom. In particular, beliefs may be shaped by classroom situations that challenge an instructor’s ability to teach effectively, including students with insufficient background preparation, the reluctance of students to review material from previous lessons before the new lesson, the diversity of the student population, and high enrollment in classes (Hativa, 1993).

Faculty beliefs about teaching are also influenced by other factors, such as the discipline to which the faculty member belongs. For example, there are significant differences between disciplines in terms of course goals, attitudes of faculty towards instruction, and practices used in the classroom that emerge from the distinctive characteristics of a discipline (Angelo & Cross, 1993; Stark, 2000). Donald (2002) acknowledged that there are differences across disciplines also in terms of ways of thinking, which in turn can influence how faculty members in each discipline approach student instruction. Stark (2000), in a survey of 2,105 introductory undergraduate course instructors, found that faculty attributed the different approaches they used in their classroom to their own scholarly background and their preparation for their career path (as either a scholar or a practitioner). Hativa (1993), looking at mathematics and the physical sciences, claimed that even highly similar science disciplines might have different disciplinary traditions and cultures that affect instruction.

Because of the tight link between teaching beliefs and practices, changing faculty beliefs about teaching is a necessary first step in reforming undergraduate education. However, changing beliefs alone is insufficient for stimulating substantive teaching reform since changing teaching practices requires a substantial investment of faculty time and energy. University faculty typically work on their teaching in isolation (Allen & Tanner, 2006), which makes it more difficult for them to learn about innovative teaching approaches and gain the confidence required to implement those approaches in the classroom. Therefore, professional development opportunities and the support of colleagues are necessary to nurture sustainable changes in undergraduate science education (Wieman, Perkins, & Gilbert, 2010).

Disciplinary Teaching and Learning Centers and Faculty Learning Communities

One of the most powerful approaches for faculty professional development in higher education has been the establishment of teaching and learning centers (Cross, 2001; Singer, 2002). Since their inception in the 1960s, teaching and learning centers have grown in scope and prominence. Some are comprehensive in nature and provide workshops, seminars, individual consultation, and a variety of other programming to support the teaching efforts of new, experienced, and future faculty (Graf, Albright, & Wheeler, 1992). Others are organized around specific educational themes such as writing, instructional technology, problem-based learning, or expansion of graduate education to include training in teaching (Singer, 2002). Teaching and learning centers play a critical supporting role in educational reform by raising faculty awareness of national recommendations and providing monetary, technical, and peer support. Furthermore, their visibility lends credibility to teaching as a scholarly endeavor (Hutchings & Shulman, 1999).

At our university, we have established a disciplinary Teaching and Learning Center (TLC) in the chemical and biological sciences that exposes faculty to nationally recommended innovative teaching approaches and then helps them incorporate these approaches in their classrooms. To facilitate this process, the TLC provides individual assistance to faculty members, including helping faculty members assess the impact of innovative teaching techniques on student learning. To encourage the integration of teaching and research among faculty, the TLC invites nationally recognized teacher/scholars to campus to present their scholarly work in teaching. The TLC also offers opportunities for faculty and graduate students to attend teaching workshops and present their research on teaching and learning at national conferences. Moreover, the TLC has been instrumental in establishing long-term Faculty Learning Communities (FLCs) that support faculty in adopting new teaching strategies and implementing major curriculum reforms.

Faculty learning communities (FLC) represent groups of colleagues (usually six to 15 people) who are engaged in the active process of learning and collaborating, and who share an enterprise that they believe is worth pursuing (Cox, 2004). For some FLCs, this can encompass creating new pedagogies, designing new curricula, and assessing the impact of educational reforms (Tagg, 2010). Most importantly, FLCs encourage faculty members to become thoughtful, reflective practitioners of teaching (Ash, Brown, Kluger-Bell, & Hunter, 2009; Henderson & Dancy, 2008; Lee, 2006; Silverthorn, Thorn, & Svinicki, 2006; Sirum, Madigan, & Klionsky, 2009; Tagg, 2010; Wenger, 1998). The ideas behind FLCs are based on the conceptual framework of the social theory of learning and communities of practice, a term coined by Lave and Wenger (1991). *Communities of practice* are defined as "groups of people who share a concern, a set of problems, a passion about a topic and who deepen their knowledge and expertise in that area by interacting on an ongoing basis" (Wenger, McDermott, & Snyder, 2002, p. 4). Wenger (1998) identified three characteristics of communities of practice: mutual engagement, a joint enterprise, and a shared repertoire. In order to be a member of a community, including an FLC, there must be mutual engagement or interactions with other members of that community. The members of the community must also be engaged in a joint enterprise or common purpose as defined by the participants. Finally, communities of practice develop routines, words, tools, actions, or concepts that serve as a shared repertoire of resources. Through these elements, communities of practice provide a way for members to engage, learn, and grow in their personal and professional development.

In this study, conducted 5 years after the creation of the TLC, we sought to investigate beliefs about, and use of, approaches that promote active engagement, as viewed by three different populations involved in undergraduate education (faculty, graduate teaching assistants [GTAs], and undergraduate students). In our institution, faculty members are the primary instructors for the lecture components of science courses, while GTAs working under the direct supervision of faculty provide most of the instruction in laboratory and recitation sections. Undergraduate students are the recipients of instruction, but they also influence instruction in that their attitudes and expectations can affect the willingness of faculty to experiment with different teaching approaches. This research is unique in capturing of the perspectives of three intertwined populations. We were interested in the perspectives of each of the three populations, because change is not only difficult for instructors (faculty and GTAs), but also for the students (Welsh, 2012).

As mentioned before, instructors' resistance to change stems from a variety of concerns. First, they fear that active learning prevents them from covering as much content as they would with lecture. Second, they lack sufficient preparation time to develop or adapt active-learning activities for their class. High course enrollment, classroom size, and inability to adjust the positions of seats further limit student engagement. Finally, faculty may worry about how their colleagues will view this new commitment to teaching reform (Sutherland & Bonwell, 1996), how student evaluations might be influenced (Qualters, 2001), and, consequently, how their promotion and tenure may be affected (Austin, 2011; Boice, 2011). Students are also resistant to change, and do not necessarily appreciate the benefits of evidence-based teaching approaches (Qualters, 2001). In a recent study of 492 science undergraduates at the University of British Columbia, only about 40% perceived in-class active learning techniques as important or very important in positively influencing their academic performance, while roughly 30% considered them unimportant or slightly important (Welsh, 2012). To our knowledge, no previous study has simultaneously examined the education goals and experiences of these three populations.

Research Questions

In spring 2011 undergraduate seniors, GTAs, and faculty in the chemical and biological sciences were surveyed to investigate the following research questions:

1. What do each of the three populations believe are the most important skills for undergraduates to acquire? Do these beliefs differ within and between populations?
2. What do faculty members believe are the most important teaching approaches? Are there differences among faculty attributable to gender, discipline, rank, or community membership?
3. What teaching approaches do faculty members report using?
4. What teaching approaches did undergraduate students experience, and are these consistent with faculty reports?
5. What professional development opportunities do faculty believe would help them with their teaching?

Methods and Data Sources

Context of the Study

Our university enrolls 25,000 undergraduate and 9,900 graduate students in 111 undergraduate and 96 graduate programs. Within the chemical and biological sciences there are 165 faculty members (32% female), about 2,400 undergraduates pursuing majors in the biological sciences, and about 400 undergraduates pursuing majors in biochemistry and chemistry. There are about 130 graduate teaching assistants (experienced and new) in biological sciences and 84 in chemistry and biochemistry. In 2006, we established a college-based Teaching and Learning Center to bring focus to teaching activities in the chemical and biological sciences and help create new opportunities for faculty and graduate student development. One of the major activities of the TLC is to help establish and support faculty teaching and learning communities. It does so by providing science education consulting, funding for faculty to attend conferences and workshops, opportunities for dissemination, and advice on grant writing and assessment. Faculty teaching and learning communities focus variously on thematically linked sequences of courses in the upper-level curriculum, gateway introductory courses, the interface between related science disciplines (e.g., bio-math, bio-physics), and the training of future faculty.

Sample

The sample included 288 undergraduate seniors who graduated in spring 2011 (approximately a 75% response rate), 99 GTAs (45% response rate), and 71 faculty members (43% response rate). The surveys were conducted online. Faculty and graduate students were recruited through direct emails that provided a link to the survey. To increase participation, the dean of the college also sent an email message to all faculty and graduate students encouraging them to complete the survey. As an additional incentive, all faculty and graduate students who completed the survey had the option of entering their names into a lottery to win a book award, with four awards offered for each population. We attribute the relatively high percent of participation to the combination of these methods. Undergraduate students in their senior year were asked to respond to the survey as part of their graduation clearance process. While completion of the survey was optional, they were encouraged to complete it as a way of providing feedback on their experiences to help the college administrators improve the undergraduate experience. They received several email reminders about the survey in the weeks leading up to graduation. The demographics of survey respondents were representative of the overall undergraduate senior, GTA and faculty populations (see Table 1).

The faculty members belonged to four departments: cell biology and molecular genetics (33%), biology (31%), entomology (8%), and chemistry and biochemistry (28%). Distribution by faculty rank was non-tenure-track lecturers (30%), professors (31%), associate professors (24%), and assistant professors (15%). Thirty-six faculty members (51% of responding faculty) reported that they belonged to at least one faculty teaching and learning community. Faculty participated in communities built around thematically-linked sequences of courses (n = 14), gateway introductory courses (n = 9), interdisciplinary teaching (n = 11), and cross-cutting campus initiatives (n = 13).

Research Instrument and Data Analysis

Three separate surveys were developed for faculty, GTAs, and undergraduates. The surveys for faculty and graduate students were anonymous, while the survey for undergraduates was not anonymous. Some items differed slightly depending on the audience; however, we tried to keep the items as similar as possible for comparison. The survey for faculty (i.e., Science Teaching Beliefs and Practices, STEP) included 28 items, the survey for GTAs included 22 items, and the survey for undergraduates included five items related to this study as well as additional questions for internal program evaluation (the surveys are available upon request from the authors). All surveys included Likert-scale questions and open-ended explanations. The surveys were developed through an iterative process and reviewed for face validity by experts in the sciences (i.e., department chairs, faculty members, and an outside evaluator), education (i.e., graduate student and statistician), and psychology (i.e., graduate student and outside evaluator). Validity and reliability were established through pilot studies (e.g., Marbach-Ad, Schaefer Ziemer, & Thompson, 2012).

Table 1
Demographic Information for Undergraduates, GTAs, and Faculty Survey Respondents

		Seniors (n = 288)	GTAs (n = 99)	Faculty (n = 71)
Gender	Female	58%	65%	37%
	Male	42%	35%	63%
Science discipline	Chemistry and biochemistry	18%	34%	28%
	Biological sciences	82%	62%	72%

In the pilot survey for faculty (STEP-pilot), we asked the participants to reflect on what is important for undergraduate students to acquire through their studies, and we included "critical thinking" as one of the options they could select. However, critical thinking represents a broad concept that encompasses multiple different learning outcomes. We felt that we needed to conduct a finer-grained analysis of educational outcomes. Therefore, in the revised survey used here (STEP), instead of asking about the value of undergraduates acquiring critical thinking skills, we asked about specific components of this larger skill (i.e., understanding the dynamic nature of science, interpreting graphs, understanding major scientific concepts, and connecting course content to everyday life and to scientific research). The specific list of skills was drawn from the responses of the faculty to the STEP-pilot survey and from national recommendations on scientific teaching as a way to develop critical thinking (Handelsman et al., 2007; Wieman, 2007). Similarly, instead of asking about using active learning in the classroom generally, we asked about specific active learning approaches such as working in groups, using real-life problems, asking students to interpret graphical information, and fostering in-class and out-of-class discussions. Previous studies have found that when instructors use these approaches, students have deeper understanding, more well developed professional skills, and greater motivation, engagement, and confidence (e.g., Gilardi & Lozza, 2009; Gulikers, Kester, Kirschner, & Bastiaens, 2008; MacFarlane, Markwell, & Date-Huxtable, 2006).

We analyzed the data using mixed-methods analysis. For qualitative analysis of the open-ended questions, we used a modified content analysis strategy (Ryan & Bernard, 2000), in which we grouped related responses into subcategories that could be quantified. A graduate student from the College of Education, a graduate student in biology, an outside evaluator from psychology, and two science education faculty members categorized the responses separately and then discussed their categories until they came to agreement. Their inter-rater agreement was 90%.

The quantitative data was obtained from the Likert-scale and multiple-choice questions. We compared beliefs between and within populations using multiple analysis of variance (MANOVA). When the overall MANOVA was significant, we followed up with univariate ANOVA on each variable of interest to identify those with significant effects. We used Tukey's HSD and *t* tests to determine significant differences between means. We investigated the factors influencing reported teaching approaches using ANOVA. The degree of agreement between the rankings of different populations was investigated with Spearman correlations. For reporting results, we provide both means and percent of responses to highlight differences between groups.

Results

Below we present the findings according to our research questions.

Research Question 1

Our RQ1 was: What do each of the three populations believe are the most important skills for undergraduates to acquire? Do these beliefs differ within and between populations? We asked faculty, GTAs and undergraduate seniors to rate the importance of several educational skills (see Table 2) on a scale of

Table 2
Senior, GTA, and Faculty Ratings of the Importance of Skills for Undergraduates

	Percentage rating skill as *important* or *very important*			Importance score		
Skills for undergraduates	Seniors	GTAs	Faculty	Seniors *M* (*SD*)	GTAs *M* (*SD*)	Faculty *M* (*SD*)
Acquiring major scientific concepts	96%	94%	99%	4.7 (0.6)	4.6 (0.7)	4.7 (0.5)
Understanding how science applies to everyday life	82%	82%	88%	4.3 (0.9)	4.3 (0.8)	4.3 (0.7)
Understanding the dynamic nature of science	85%	83%	84%	4.4 (0.8)	4.3 (0.8)	4.3 (0.8)
Honing scientific writing	78%	81%	83%	4.2 (0.9)	4.2 (0.8)	4.3 (0.8)
Learning basic sets of lab skills	89%	69%	61%	4.4 (0.7)	3.9 (1.0)	3.7 (1.0)
Working in groups	50%	70%	55%	3.3 (1.2)	3.9 (1.0)	3.5 (1.1)
Memorizing basic facts	72%	46%	30%	4.0 (0.9)	3.3 (1.0)	3.0 (1.0)
Remembering formulas, structures, and procedures	49%	24%	19%	3.4 (1.1)	2.8 (1.0)	2.6 (1.0)

Note. Percentages reflect combined categories 4 (*important*) and 5 (*very important*).

1 to 5, where 1 = *not important* and 5 = *very important*. In reporting the percentage of participants who placed importance on each skill, we combined categories 4 (*important*) and 5 (*very important*).

A large majority of the three populations rated the following skills as important or very important: acquiring major scientific concepts (faculty = 99%, GTAs = 94%, seniors = 96%), understanding how science applies to everyday life (faculty = 88%, GTAs = 82%, seniors = 82%), understanding the dynamic nature of science (faculty = 84%, GTAs = 83%, seniors = 85%), and hone scientific writing (faculty = 83%, GTAs = 81%, seniors = 78%). All of these skills align with national recommendations for science education, and some of them are specific to science disciplines (i.e., understanding the dynamic nature of science and scientific writing) and are integral to conducting scientific research.

Seniors differed from faculty and GTAs in their ratings of memorizing basic facts (faculty = 30%, GTAs = 46%, seniors = 72%), learning basic sets of lab skills (faculty = 61%, GTAs = 69%, seniors = 89%) and remembering formulas, structures, and procedures (faculty = 19%, GTAs = 24%, seniors = 49%). Seniors rated memorization, lab skills, and learning formulas as significantly more important than did faculty ($F = 31.92$, $df = 425$, $p < .001$; $F = 20.34$, $p < .001$; $F = 21.64$, $p < .001$, respectively) and GTAs ($F = 19.30$, $df = 425$, $p < .001$; F = 29.67, $p < .001$; $F = 22.79$, $p < .001$, respectively). We suspect that seniors were more likely to consider these skills important because it reflects the way that they approached learning as undergraduates. Especially in the introductory courses, but also in many of the upper-level courses, they are required to memorize scientific terminology, facts, and technical procedures. At the graduate level, we believe that students have already developed this foundation and can move beyond it.

A higher percentage of graduate students (70%) rated working in groups as important as compared to seniors (50%) and faculty (55%). GTAs rated group work as significantly more important than seniors ($F = 10.94$, $df = 425$, $p < .001$), while faculty were intermediate and did not differ significantly from either of the other groups. Given the collaborative nature of modern science, it is not surprising that the majority of graduate students recognize the importance of group work. However, it was surprising that faculty members and seniors did not give group work higher importance. This may reflect the logistical difficulties of designing and facilitating productive group work in large undergraduate classes, which may influence the attitudes of seniors and faculty towards group work.

MANOVA revealed no significant main effect or interaction effect for gender across all three populations. Across all three populations, those in the chemical sciences rated learning basic sets of lab skills and remembering formulas, structures, and procedures as significantly more important than those in the biological sciences, $F = 18.43$, $df = 425$, $p < .001$ and $F = 28.62$, $df = 425$, $p < .001$, respectively.

Research Question 2

Our RQ2 was: What do faculty members believe are the most important teaching approaches? Are there differences among faculty attributable to gender, discipline, rank, or community membership? We asked faculty to rate the importance of various teaching approaches (see Table 3) on a scale of 1 to 5, where 1 = *not important* and 5 = *very important*. The three teaching approaches that faculty rated as having the greatest importance were communicating course goals and objectives to students, relating course material to scientific research, and relating course material to real world applications ($M \geq 4.0$). Extensive lecturing was rated as the least important teaching approach ($M = 2.6$).

We explored whether faculty characteristics predicted their rating of the importance of these

Table 3

Means and Standard Deviations for Faculty Ratings of the Importance of Various Teaching Approaches for Educating Undergraduate Students

Importance of approach to teaching undergraduate students	*M* (*SD*)
Communicating course goals and objectives to students	4.4 (0.7)
Relating course material to scientific research	4.1 (0.7)
Relating course material to real world applications	4.0 (0.8)
Using different types of teaching methods	3.8 (1.0)
Gauging students' background knowledge	3.7 (0.9)
Using different types of assessments for grades	3.5 (1.2)
Using ungraded assessments to give students feedback	3.1 (1.2)
Using a historic perspective	3.0 (1.0)
Using extensive lecturing	2.6 (1.0)

Note. Rated on a scale from 1 (*not important*) to 5 (*very important*).

approaches. We conducted a MANOVA with the following faculty characteristics as predictors: gender, membership in a community, faculty rank (lecturers vs. tenure-track), discipline, course type (lab vs. lecture), course level (introductory vs. upper level), course size (< 60 students vs. > 60 students). Because of the large numbers of potential predictor variables, we conducted a backwards stepwise procedure to identify the subset of predictors with greatest explanatory power. By this procedure, gender, discipline, course type, course level, and course size were eliminated from the overall model, leaving membership in a community ($F = 2.7241$, $df = 9, 52$, $p = .0111$) and faculty rank ($F = 2.9412$, $df = 9, 52$, $p = .0067$) as significant predictors.

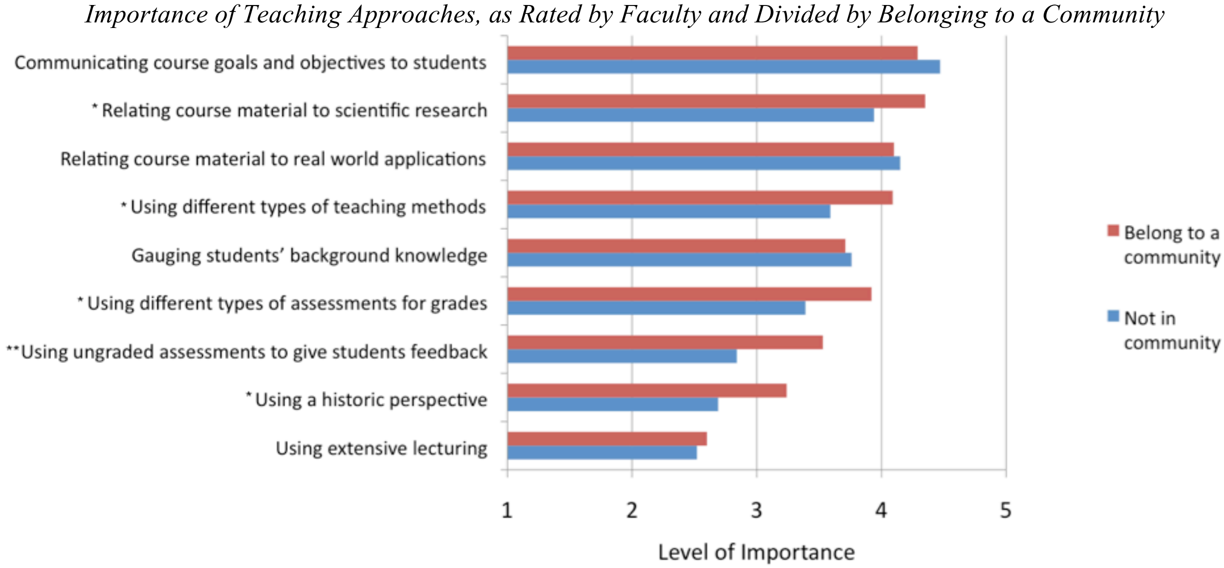
Faculty who were members of a teaching community rated the following approaches as significantly ($p < .05$) more important than those who were not members of a community (see Figure 1): relating course material to scientific research (community = 4.3 ± 0.6; not community = 3.9 ± 0.7), using different types of teaching methods (4.1 ± 0.8 and 3.6 ± 1.1, respectively), using different types of assessments for grades (3.8 ± 1.0 and 3.4 ± 1.2, respectively), using ungraded assessments to give students feedback (3.5 ± 1.0 and 2.7 ± 1.2, respectively), and using a historic perspective (3.3 ± 1.0 and 2.7 ± 0.9, respectively). All of these approaches are considered best practices by recent national recommendations.

Lecturers rated the following approaches as significantly ($p < .05$) more important than tenure-track faculty (see Figure 2): communicating course goals and objectives to students (4.6 ± 0.5 and 4.2 ± 0.7, respectively), using different types of teaching methods (4.1 ± 0.8 and 3.6 ± 1.0, respectively), using different types of assessments for grades (4.1 ± 0.9 and 3.3 ± 1.1, respectively) and using ungraded assessments to give students feedback (3.5 ± 1.3 and 2.9 ± 1.1, respectively). These differences were independent of membership in a faculty teaching community.

Research Question 3

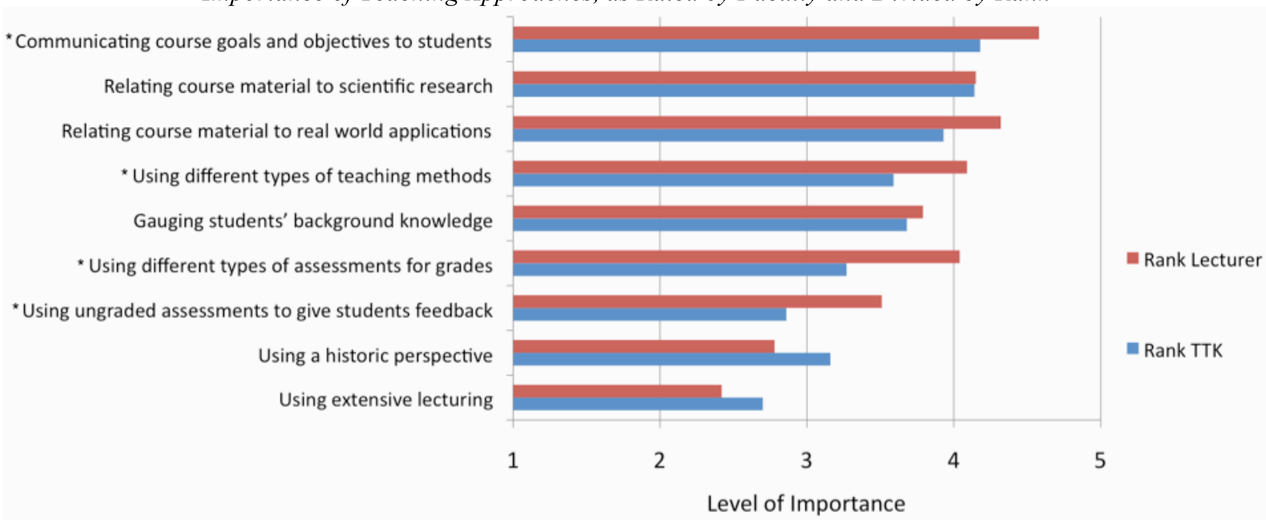
Our RQ3 was: What teaching approaches do faculty members report using? We asked faculty members how often they used each of 16 teaching approaches (Table 4) on the following scale: 1 = *not used*, 2 = *once per semester*, 3 = *a few times a semester*, 4 = *most class sessions*, and 5 = *almost every class session*. Table 4 shows the means of the scaled responses. The five teaching approaches that faculty reported using the most frequently included answering questions from individual students in class (4.6 ± 0.5), extensive lecturing (4.5 ± 0.8), communicating course goals and objectives (3.5 ± 0.9), asking students to interpret graphical information (3.4 ± 1.0), and class discussions (3.4 ± 1.2). The least used teaching approach was reflective writing/journaling (1.4 ± 0.8). Teaching approaches that were used with intermediate frequency included group work during class (2.4 ± 1.3) or outside of class time (2.4 ± 1.4). Faculty reported

Figure 1
Importance of Teaching Approaches, as Rated by Faculty and Divided by Belonging to a Community



Note. Rated on a scale from 1 (*not important*) to 5 (*very important*).
*$p < .05$. **$p < .01$.

Figure 2
Importance of Teaching Approaches, as Rated by Faculty and Divided by Rank



Note. Rank divided by lecturer vs. tenure and tenure-track faculty (TTK). Rated on a scale from 1 (*not important*) to 5 (*very important*).
$^*p < .05$.

Table 4
Faculty Responses to Their Use of Classroom Teaching Approaches

Teaching Approaches Faculty Report Using	*M* (*SD*)
Answering questions from individual students in class	4.6 (0.5)
Extensive lecturing	4.5 (0.8)
Communicating course goals and objectives	3.5 (0.9)
Asking students to interpret graphical information	3.4 (1.0)
Class discussions	3.4 (1.2)
Multimedia instruction	2.8 (1.2)
Real-life problems	2.5 (1.3)
Group work during class time	2.4 (1.3)
Group work outside of class time	2.4 (1.4)
Debates in class	2.0 (1.2)
Out of class discussions	2.1 (1.4)
Personal Response System	2.0 (1.6)
Graphic organizers	1.6 (1.0)
Online modules with immediate feedback	1.6 (1.2)
Games, simulations, role-play	1.5 (0.9)
Reflective writing/journaling	1.4 (0.8)

Note. Means were calculated based on the following scale: 1 = *not used*, 2 = *once per semester*, 3 = *a few times a semester*, 4 = *most class sessions*, and 5 = *almost every class session*.

using group work less frequently than might be expected given the emphasis on the importance of collaboration in the science education literature. This tendency is in accord with faculty's lower rating of group work importance (see RQ1). We found strong correlations between faculty's rated importance of group work and its use in class and outside of class, $r = .46$, $p < .01$ and $r = .31$, $p < .05$, respectively.

To investigate the effect of our predictor variables on use of different teaching approaches, we subdivided the approaches into two categories. The first category consisted of fairly traditional, teacher-centered approaches (extensive lecturing, communicating course goals, answering questions from individual students), while the second category consisted of the remaining 13, more student-centered approaches. For each category, we created an index variable consisting of the sum of the ratings for the frequency of use of the approaches within that category. Faculty who belonged to a community used student-centered approaches more frequently than did faculty who did not belong to a community, $F = 4.97$, $df = 1, 47$, $p < .05$ (see Figure 3). There was no effect of belonging to a community on the frequency of use of teacher-centered approaches.

To understand how communities promote the use of these teaching approaches, we analyzed faculty's qualitative responses (n = 18) about the benefit of community participation. Although we had a small sample size, three main themes emerged from faculty's qualitative responses:

1. The community provided faculty with the opportunity to learn from others' experience: "This community gets me thinking about ways to make my teaching more interesting and more effective. I get ideas that I don't get any other place"; and, "I gain ideas that I can implement in my classes and share with colleagues."
2. The community enhanced funding opportunities available to groups of faculty to develop innovative activities: "The community also provide synergistic interactions and brainstorming opportunities that often result in grant proposals to further our efforts"; and, "Our group has acquired funding to help our curriculum development initiatives, and I have been able to attend several conferences as a result."
3. The community promoted synergy between lecturers and tenure-track faculty. A tenure-track faculty member reflected, "As a researcher who teaches, I learn about the field of science education and current approaches to improve learning and literacy." One of the lecturers noted that the collaboration with tenure-track faculty allowed her to bring cutting-edge research into the classroom.

Research Question 4

Our RQ4 was: What teaching approaches did undergraduate students experience, and are these consistent with faculty reports? Students were asked how often their instructors used each of the 16 teaching approaches (see Table 5) using the following scale: 1 = *none of my courses*, 2 = *rarely*, 3 = *sometimes-mostly in introductory courses*, 4 = *sometimes-mostly in upper-level courses*, and 5 = *in most courses*. In order to compare faculty responses and students' responses, we combined the top three categories in each scale. For students, the combined categories 3, 4, and 5 reflected teaching approaches that were encountered at least sometimes in the undergraduate curriculum. For faculty, the combined categories of 3, 4, and 5 reflected teaching approaches that were used at least a few times

Figure 3
Frequency of Reported Use of Teacher-Centered and Student-Centered Instructional Approaches by Faculty Members Belonging to Teaching Communities and Those Not Belonging to Communities

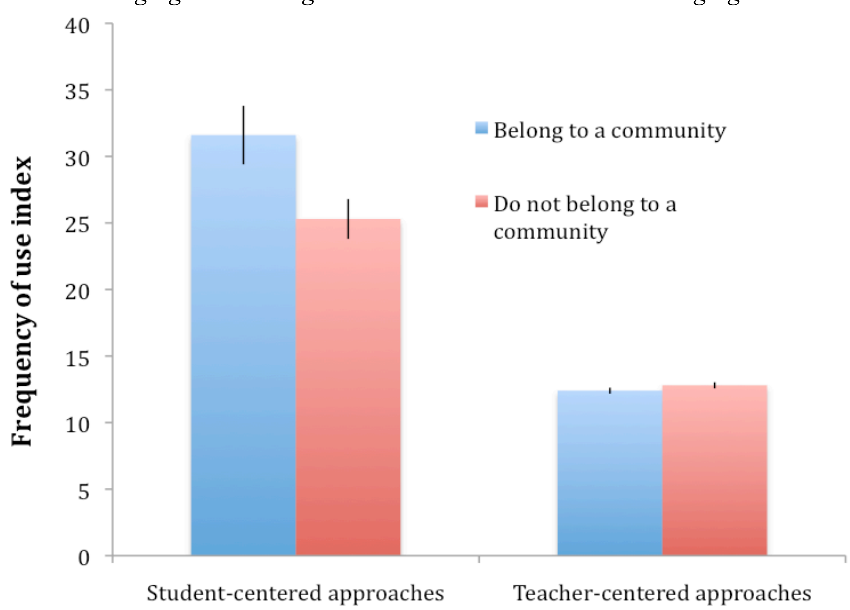


Table 5
Ranking of the Teaching Approaches Reported by Faculty and Seniors Based on Percentages of the Combined Top Three Categories

Teaching approach	Faculty (%)	Rank	Seniors (%)	Rank
Answering questions from individual students in class	100	1	82	4
Extensive lecturing	98	2	95	2
Communicating course goals and objectives	90	3	95	1
Asking students to interpret graphical information	90	4	84	3
Class discussions	87	5	74	7
Multimedia instruction	72	6	73	8
Real-life problems	61	7	75	6
Group work during class time	53	8	56	11
Group work outside of class time	49	9	69	9
Debates in class	39	10	33	14
Out of class discussions	38	11	39	13
Personal Response System	30	12	82	5
Graphic organizers	28	13	47	12
Online modules with immediate feedback	21	14	63	10
Games, simulations, role-play	18	15	18	16
Reflective writing/journaling	12	16	29	15

Note. Percentages for faculty included the responses of *a few times a semester*, *most class sessions*, and *almost every class session*, while those for seniors included *sometimes-mostly in introductory*, *sometimes-mostly in upper level*, and *in most courses*.

a semester in the faculty member's course. The scales for the two populations are not completely analogous because faculty members reported on one course that they taught, whereas seniors reported on their collective undergraduate experience; however, they do provide insight into the faculty and student perceptions of the prevalence of different teaching practices.

The four most frequently used teaching approaches reported by both students and faculty were answering questions from individual students in the class, extensive lecturing, communicating course goals and objectives, and asking students to interpret graphical information. The two teaching approaches that both faculty and students reported were least frequently used were games, simulations and role-play, as well as reflective writing/journaling. There were two teaching approaches in which there was a large discrepancy between faculty and student reports: online modules with immediate feedback and personal response system (students = 63%, faculty = 21% and students = 82%, faculty = 30%, respectively). We attribute this difference to the fact that faculty reported only on one of their courses, which could have been a lab course or small class, whereas the students reported on their collective experience across their entire undergraduate degree program. When we looked at the individual response categories, we found that these two teaching approaches were encountered by students mostly in introductory courses.

We ranked the teaching approaches according to their frequency of use as reported by students and faculty (see Table 5). These rankings were highly correlated ($r = .82$, $p < .001$); therefore, the student reports provide corroboration for faculty reports on the teaching approaches that are used in the classroom.

Research Question 5

Our RQ5 was: What professional development opportunities do faculty believe would help them with their teaching? We explored faculty ideas for professional development opportunities through an open-ended question. Of the 23 faculty members that responded to this question, six reported that they would benefit from joining a community with responses such as the following:

> We need to improve coordination among classes. There still appears to be a significant problem with redundancy, apparently driven by variation in what students learn from class to class. I will admit that I'm really not sure what knowledge instructors in subsequent classes expect students to come away from my class with.

Another faculty member responded, "I would think that working groups would help, where a period of time is used to develop a course in a group with someone experienced who can give feedback about the course organization." Five suggested that they would benefit from seminars and "workshops on targeted topics and retreats on science education." Three faculty members suggested that it would be helpful to have more funding for "graduate students who can work on projects with faculty, statistics support, helping in reviewing data." Two faculty members thought they would benefit from feedback and class observation, which could provide "feedback on teaching from an impartial observer; instruction on developing exams that truly evaluate student understanding of material." Two faculty members felt that there needed to be more recognition of teaching by the university. Finally, seven faculty members reported that they either could not think of anything or no changes were necessary.

Discussion

In this study, we sought to investigate the perceived importance of skills for undergraduate science students as viewed by three different populations involved in undergraduate education (faculty, GTAs, and undergraduate students). We also explored the reported teaching approaches used by faculty and experienced by students to investigate the extent to which active-learning, student-centered methods were being incorporated into the undergraduate curriculum. The recent science education literature emphasizes the importance of using evidence based teaching practices, in which students are engaged in their learning process (e.g., Freeman et al., 2007; Injaian et al., 2011; Jenson & Lawson, 2011; Kitchen et al., 2003; Knight & Wood, 2005; Senkevitch et al., 2011; Udovic et al., 2002; Walker et al., 2008). The science education community has also recommended modeling science instruction after how practicing scientists work, think and communicate (e.g., Handelsman et al., 2007; White House Office of the Press Secretary, 2009; Wieman, 2007), which helps students develop their understanding of the dynamic nature of science and increases their scientific problem-solving abilities (DebBurman 2002; DiCarlo, 2006; Durning & Jenkins, 2005; Zamorski 2002). This approach places a heavy emphasis on collaboration, scientific communication, and the achievement of deep conceptual understanding rather than memorizing disconnected facts.

The literature has also broadly discussed the importance of faculty awareness of the value of using best practices before they could adopt these practices and use them in their classrooms (Martin & Balla, 1991; Prosser et al., 1994; Trigwell et al., 1994; Trigwell et al., 1999). Faculty who believe in the value and decide to adopt innovative, student-centered practices usually need a support system to create and sustain the change. In our study, it was encouraging to discover that most of our faculty agree on the importance of using active learning approaches. However, we found that many continue to use traditional instruction such as extensive lecturing. From our experience, in many cases faculty are interested in implementing more effective pedagogical approaches, but they often lack the training and support to do so successfully (Marbach-Ad, Schaefer Ziemer, Thompson, & Orgler, 2013).

In summarizing the results we will refer to the three actions that are recommended by national calls (AAAS, 2010; AAMC-HHMI, 2009; AAU, 2011; National Academies, 2006; NRC, 2003; PCAST, 2012; Woodin et al., 2010) to promote critical thinking: (a) promoting conceptual understanding rather than memorization of isolated facts, (b) encouraging cooperative and collaborative learning, and (c) fostering an understanding of the nature of scientific research and its applicability to everyday life. We will discuss possible reasons for the gaps between the recommendation in the literature, faculty awareness of these goals, and their use of the relevant teaching approaches to achieve them.

Promoting Conceptual Understanding Rather than Memorization of Isolated Facts

In our study, all three populations placed a high value on conceptual understanding. This is in accord with national recommendations to promote students' conceptual understanding over rote memorization (Ebert-May, 2008; Mayer, 2002; Redish, 2003, Smith et al., 2008; Wieman 2007). However, the three populations differed in the importance they placed on memorizing basic facts. Students rated this skill as more important than GTAs or faculty. This corresponded with the prevalence of extensive lecturing in the classroom as reported by both students and faculty. The literature provides evidence that lecturing tends to affirm the value of memorizing facts (Biggs, 1999). We believe that because most students experience this frequently in the classroom, they tend to place great emphasis on this skill. As for faculty members, although they do not value memorization highly, they continue to use lecture extensively in the classroom, which reinforces the students' perception of the importance of memorization. Faculty reliance on lecturing could stem from their previous experiences as students (Anderson & Helms, 2001), lack of formal training in teaching (Adamson et al., 2003), large class sizes, pressure to cover increasing amounts of material in a limited amount of time, insufficient preparation time, fear of negative student reactions to active-learning approaches, and lack of confidence to implement new instructional approaches (Henderson, Dancy, & Niewiadomska-Bugaj, 2012; Wieman, 2007).

Interestingly, we found that there were disciplinary differences in terms of the importance placed on memorization skills. In the chemical sciences, all three populations placed a higher importance on learning basic sets of lab skills and remembering formulas, structures, and procedures as compared to those in the biological sciences. This is congruent with the research of Hativa (1993), who found that scientific disciplines operate according to different sets of rules that might differentially affect instruction in these fields. This suggests that there may be differences among disciplines in faculty willingness to move away from lecture-based instruction.

Although almost all faculty reported that they relied extensively on lecturing, most of them also reported that they frequently answered student questions in the classroom, communicated course goals and objectives, asked students to interpret graphical information and engaged students in class discussions. The emphasis on communicating course goals may be attributable to our institution's recent reaccreditation process, which resulted in a campus-wide requirement for departments to report to a university committee regarding learning outcome assessments in relation to explicit learning goals.

Encouraging Cooperative and Collaborative Learning

Cooperative and collaborative learning is one of the foundations of active learning, and there is abundant evidence that working in groups enhances student learning at the pre-college (e.g., Johnson, Maruyama, Johnson, Nelson, & Skon, 1981; Slavin, 1983, 1990) and post-secondary (e.g., Cooper, 1989; Cooper, 1995; Ebert-May, Brewer, & Allred, 1997; Hake, 1998; Treisman, 1992) levels. Moreover, group work closely reflects the practice of science in both academia and industry and allows students to develop interpersonal skills essential for the workplace (Froyd, 2008; Wood, 2009). Students working in groups often achieve a synergy that enables their collective ideas to surpass those of any individual student working alone (Froyd, 2008).

In light of the widespread agreement regarding the importance of working in groups, it is surprising that only about half of the faculty and undergraduates we surveyed placed importance on working in groups for undergraduates. Moreover, only about half of faculty reported that they asked their students to work in groups, either in class or outside of class. We suspect that this disconnect between the actual and perceived value of group work stems from a variety of factors.

Group work can be impeded by the size and structure of the classroom (e.g., forward-facing, immovable seats), but SCALE-UP (i.e., student-centered active-learning environments for undergraduate programs) rooms that are specifically designed to allow group work are becoming more prevalent. There are also cases of successful implementation of group work in traditional, lecture-style classrooms with enrollments up to 200-250 students. For example, Sokolove and Marbach-Ad (1999) found that students in a high enrollment introductory biology class who reported studying with classmates earned better test scores. They further showed that using cooperative learning methods in the classroom can significantly impact out-of-class student study behavior; students enrolled in an introductory biology class that made frequent use of cooperative, active learning activities were more likely to study together outside the classroom than students taught in a traditional lecture-style class.

Students often express frustration that they need to work harder to compensate for group members who are not putting in the required effort. Group work often is assessed as a whole, with each student in the group receiving the same grade. This makes it difficult for faculty to give adequate credit to those who made the largest contributions to the final product. Group assignments also need to be carefully constructed so that the efforts of all group members are necessary to successfully complete the assignment, and there need to be mechanisms for holding each group member accountable for their contributions (Froyd, 2008).

Encouragingly, in this study we found strong correlations between the faculty's belief about the importance of working in groups and the use of group work as an instructional technique. Those who believed that this skill was important (about half of the faculty) also used this approach more frequently in their classrooms. This provides hope that increasing faculty awareness of the benefits of group work, along with the increasing use of technology to foster collaboration and the advent of large lecture rooms that allow students to assemble into groups, will result in an increase in the prevalence of group work as a teaching strategy.

Fostering an Understanding of the Nature of Scientific Research and Its Applicability to Everyday Life

Recent national recommendations stress the importance of approaching scientific education with the same rigor as scientific research and using examples from everyday life and scientific research in their teaching (AAAS, 2010; Handelsman et al., 2007). There are many ways of accomplishing this, including the use of case studies (e.g., CASES Online, 2014; Herreid, 2005; National Center for Case Study Teaching in Science, 2014), problem-based learning (e.g., Allen & Tanner, 2003; University of Delaware, 2014), and course-embedded scientific reading and writing (e.g., Ebert-May & Hodder, 2008; Mulnix, 2003; Parent, Marbach-Ad, Swanson, & Smith, 2010).

We were encouraged to find that the large majority of faculty and graduate students placed a high level of importance on scientific writing, understanding the dynamic nature of science, and understanding how science applies to everyday life.

We found a gap, however, between faculty beliefs about the importance of undergraduates acquiring scientific writing skills and the faculty's use of scientific writing in undergraduate courses. Although faculty reported that they valued scientific writing, only about one-third reported that they gave assignments that involved writing. Marbach-Ad and Arviv-Elyashiv (2005) found that biology faculty agreed on the importance of undergraduates acquiring scientific writing skills; however, faculty disagreed about whether scientific writing should be taught in special courses through the English department or incorporated into assignments in science courses. Other studies have found that a lack of human resources to read and provide feedback on students' writing assignments deters faculty from incorporating scientific writing assignments in their courses (Marbach-Ad et al., 2013).

Most faculty members felt it important to relate course material to everyday life and to scientific research. In terms of teaching approaches, a large majority of faculty reported that they used real-life problems and asked students to interpret graphical information at least a few times per semester. The high percentages of both beliefs and reported use of these teaching approaches may be due to the growing availability of libraries of case studies

The Role of FLCs in Assisting Faculty to Adopt Evidence-Based Teaching Approaches

Successful implementation and institutionalization of active learning teaching techniques in higher education requires comprehensive, ongoing support for faculty that must be situated in the broader context of institutional and departmental cultural change (Wieman, 2007). It is naïve to expect that isolated professional development experiences will result in lasting change without continued reinforcement and peer support (Ebert-May et al., 2011). This support can take the form of mentoring and feedback from expert teachers (Ebert-May et al., 2011; Henderson, Beach, & Famiano, 2009) or participating in a community of practice (Rogan, 2007). When we looked at the faculty's reported use of an array of teaching approaches, we found differences between faculty who belonged to FLCs and those who did not, which we believe are connected to the FLCs' activities. Faculty who belonged to a FLC reported using student-centered teaching approaches more frequently than faculty who did not belong to a community. Silverthorn et al. (2006) also found that faculty members who participate in FLC change their teaching approaches by including more classroom activities, using more assessments, and reconfiguring their teaching content. These changes in teaching translate into greater student engagement, more opportunities for students to reflect and self-assess their learning, more opportunities for students to integrate information, more positive student evaluations, and a better classroom environment (Cox, 2004; Silverthorn et al., 2006). In our study, for example, we found that faculty who participated in communities reported using group work in and outside of the classroom significantly more often than those who were not in a community. Communities are themselves a type of group, and therefore it makes sense that faculty who benefit from participating communities recognize the potential importance of group work for students.

Recommendations for Change

We believe that in order to further assist faculty members, it is necessary to provide them with professional development opportunities, moral support from peers, and instructional support from science education and instructional technology specialists. Here we suggest broad recommendations for professional development activities and describe how we made use of the survey results at our College of Chemical and Life Sciences.

To enhance professional development opportunities for faculty and graduate students, our College of Chemical and Life Sciences initiated a disciplinary Teaching and Learning Center that develops activities based on survey data and informal conversations with faculty and graduate students. Programming includes teaching and learning workshops that focus on topics relevant to STEM education. For example, the TLC runs a visiting teacher/scholar seminar series that highlights scientists who are nationally recognized for their ability to integrate teaching and research. Visiting teacher/scholars spend 2 days on our campus sharing their ideas and meeting with small groups of faculty for informal discussion. We feel that this dual emphasis on teaching and scientific research provides a model for how faculty at large research universities can engage in scholarly teaching.

Another way of enhancing professional development is through faculty learning communities that meet regularly to discuss teaching and learning initiatives. These communities facilitate productive collaborations between lecturers (who have primarily instructional responsibilities) and tenure-track faculty (who have both research and instructional responsibilities). They also provide opportunities for experienced instructors to mentor novice instructors. The teamwork that develops within communities also helps faculty to save time in developing teaching materials and exploring the use of innovative pedagogies, as well as making it easier for them to get grant support for these initiatives. The TLC is also trying to involve graduate students in the communities so that they will have more opportunities for professional development in teaching and learning. To better prepare future faculty members, the college invests in graduate teaching assistant training. All new graduate students are required to participate in a prep course for science teaching, and a more extensive program exists for graduate students who are interested in teaching and learning for their career.

The Teaching and Learning Center is working closely with department chairs and faculty to develop a peer review evaluation framework for all faculty in the department. Peer review, which is usually used only for summative purposes (e.g., merit and promotion), can also be used to create a regular feedback process in which all faculty members are observed and participate as observers for other faculty.

This study provides a unique contribution to the science education literature since it captures the perspectives of the three populations involved in undergraduate science education in our college: undergraduates, GTAs, and faculty. The findings from this study, and the professional development activities inspired by it, can serve as a model for other universities and colleges by indicating what is missing from undergraduate science education and highlighting fruitful avenues for professional development in teaching and learning.

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Acknowledgments

The preparation of this manuscript was supported by grants from the Howard Hughes Medical Institute Undergraduate Science Education program and the National Science Foundation Course, Curriculum and Laboratory Improvement program (DUE-0942020). This work has been approved by the Institutional Review Board as IRB Protocol #: 07-0021. We thank Jeffrey Harring and Xiaoshu Zhu from the Department of Measurement, Statistics & Evaluation (EDMS) in University of Maryland for their assistance in developing the surveys. We also thank all faculty, graduate students and undergraduates who participated in this study.